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Geothermal- And Solar Assisted Air Conditioning System

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ABSTRACT

A research project of the Hamburg University of Technology realizes an open cycle desiccant assisted air conditioning system based on renewable heat sources e.g. solar thermal and heat sinks e.g. shallow geothermal energy. Both advantages of the open cycle process are taken into account, the possible use of a heat sink at higher temperatures and the use of low calorific heat. Moreover, the total system combines additional aspects of an energy efficient air conditioning system e.g. ventilation fan control, a bypass system to reduce extra pressure losses and space heating / cooling. All pumps of the system are frequency controlled and belong to the group of energy-saving pumps. The geothermal system comprises 3 boreholes with a depth of 75 m (246ft) and 5 energy piles with a depth of 14 m (46ft) and supplies the cooling energy for the air conditioning system. A solar thermal system with 20 m² flat panels supplies the low calorific heat. By using space heating e.g. floor heating and the space cooling e.g. floor cooling, cooling beams even more energy can be saved by the separation of cooling and ventilation due to the higher heat capacity of water.

This paper presents the results of the demonstration plant for the years 2009 and 2010. The influences of several aspects of an energy efficient air conditioning system combined with a demand oriented control system are presented as well as experiences in dynamic modeling.

1. INTRODUCTION

Due to the steadily increasing amount of guidelines for energy savings in Germany, especially the Energy Saving Ordinance for Buildings, the heat demand of buildings in Germany has steadily decreased in the past years. Even new office buildings with glass structured surfaces can realize a low heat demand through better insulation. However, the improved insulation often results in an increasing demand of cooling capacities even in milder climate zones e.g. Northern Germany. In a conventional air conditioning system, outside air is cooled below the dew point to remove the latent loads. Condensing out water from the air requires large cooling capacities, which are often provided by electric compression chillers and lead to high electricity consumptions.

In an open cycle desiccant assisted air conditioning system the dehumidification and cooling can be separated within the process. Moist air is dehumidified by means of a solid or liquid desiccant. Afterwards, the hot dry air can be cooled by a heat sink at higher temperature level e.g. 16 °C (60.8 °F). For the regeneration of the desiccant wheel low calorific heat is acceptable. The electricity demand is replaced by an additional heat demand.

A research project of the Hamburg University of Technology realizes an ecological and energy efficient air conditioning system in Northern Europe, Hamburg. The system introduced in this paper based on a combination of an open cycle desiccant assisted air conditioning system and a dedicated outdoor air system (DOAS) (Larranaga, Beruvides, Holder, Karnuasena, & Strauss, 2008; Mumma & Ph, 2001).
The use of shallow geothermal energy as heat sink and solar thermal energy as heat source enables an ecological air conditioning system.

An open cycle desiccant air condition system is already introduced by Smith (1940). Smith invented an air conditioning system, where cooling and dehumidification of the supply air stream is separated. Later, this advantage was used by Maclaine-Cross & Airah (1987) to build a gas-fired hybrid desiccant cooling unit to reduce the costs and to allow a heat driven air conditioning system. Furthermore, the definition of a hybrid desiccant system, which separates cooling and dehumidification is introduced.
Anyway, the cooling is still be done by a vapor compression chiller. In the following years many other desiccant assisted air conditioning systems mainly with evaporation cooling or vapor compression chiller were introduced. A good overview can be found in Parmar & D.A.Hindoliya (2011).
For a low energy cooling system it is efficient to reduce the air stream to a minimum and therefore separate cooling and ventilation. The air-water air conditioning systems are already well known and introduced in Germany in early 1960^{th} (Rudolph and Wagner 2008).The basic idea can be found as well in the dedicated outdoor air systems. The main advantage of these systems is the reduction in the supply air stream and therefore the separation of ventilation and cooling/ heating. The minimum air flow stream depends on several conditions and differs over the past years. The change can be seen in the different definitions for the minimum air flow rate by ASHRAE-62 which is summarized in Janssen (1999). The system introduced in this paper reduces the air stream to a comfortable minimum based on studies from Berglund (1998) and Fanger (2001).

The following concept combines the aspects in one system (see **Figure 1**). The desiccant assisted air conditioning system allows the reduction of the air stream due to the separation of cooling and dehumidification. Additional, due to the dehumidified air, radiant cooling/ heating systems can be used without limitations. Low calorific heat can be used for the desiccant system in the summer and for the radiant heating in the winter. The separation of cooling and dehumidification allows the use of heat sinks with temperatures above 16 °C (60.8 °F) e.g. shallow geothermal energy. This kind of heat sinks can be an ideal completion to the radiant cooling systems.

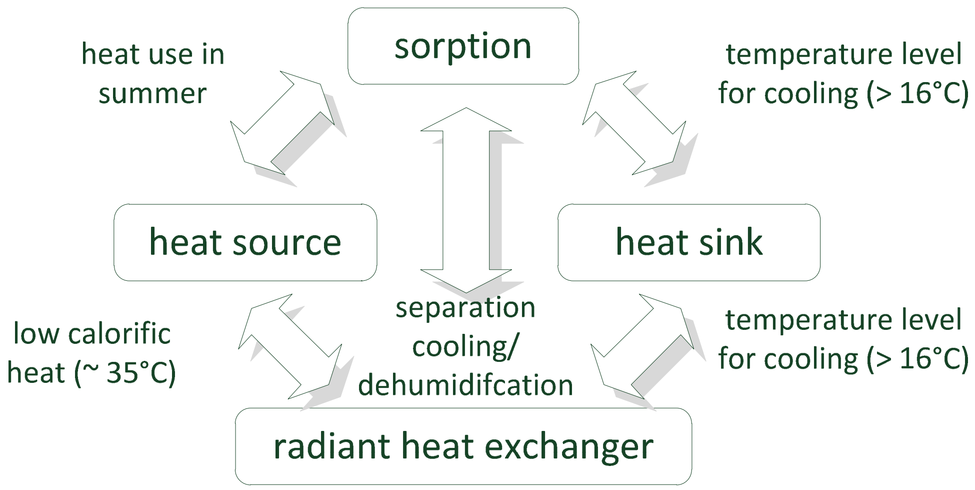

Figure 1: Advantages of a desiccant assisted air conditioning system in combination with a radiant heat exchanger and renewable heat sinks and heat sources.

The pilot installation located in Hamburg, Germany can be seen in seen in **Figure 2**. The complex is divided into an office section of four 20ft container (**Figure 2**, front) and two 20ft container with the technical installations (**Figure 2**, back). The office area is separated from the technical installation and used as reference room for the air conditioning system.

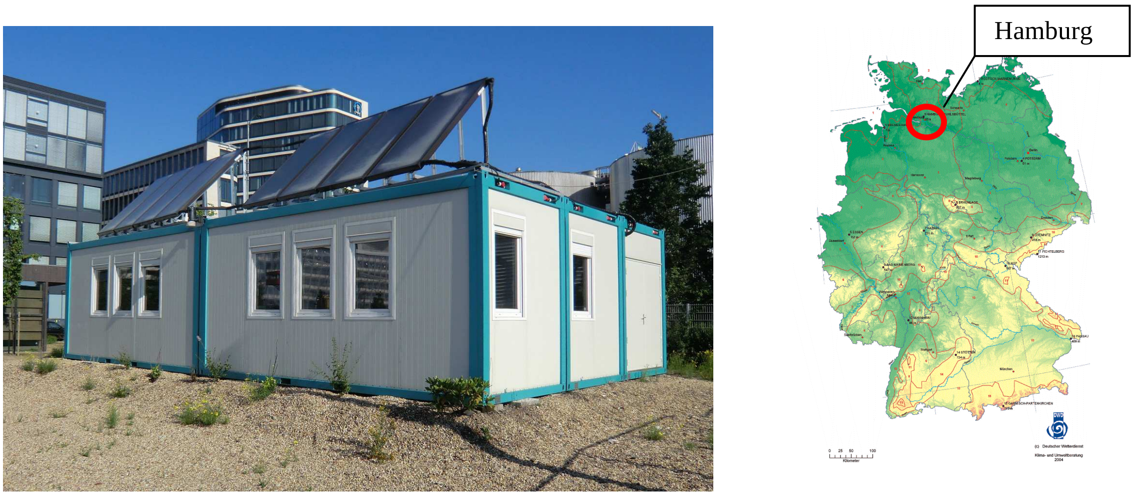

Figure 2: Picture of a pilot plant of a hybrid desiccant assisted air conditioning system in Northern Europe, Hamburg HafenCity.

On the roof of the office building solar thermal flat panels with an area of 20 m² are installed. The shallow geothermal energy is integrated by five energy piles with a depth of 14 m (46ft) each and 3 bore hole heat exchangers with a depth of 75 m (246ft) each. The pilot plant is connected to the city district heating network.
A heat pump connected on the condenser side to the warm water circuit and on the evaporation side to the cold water circuit can be used as additional heat sink or heat source.

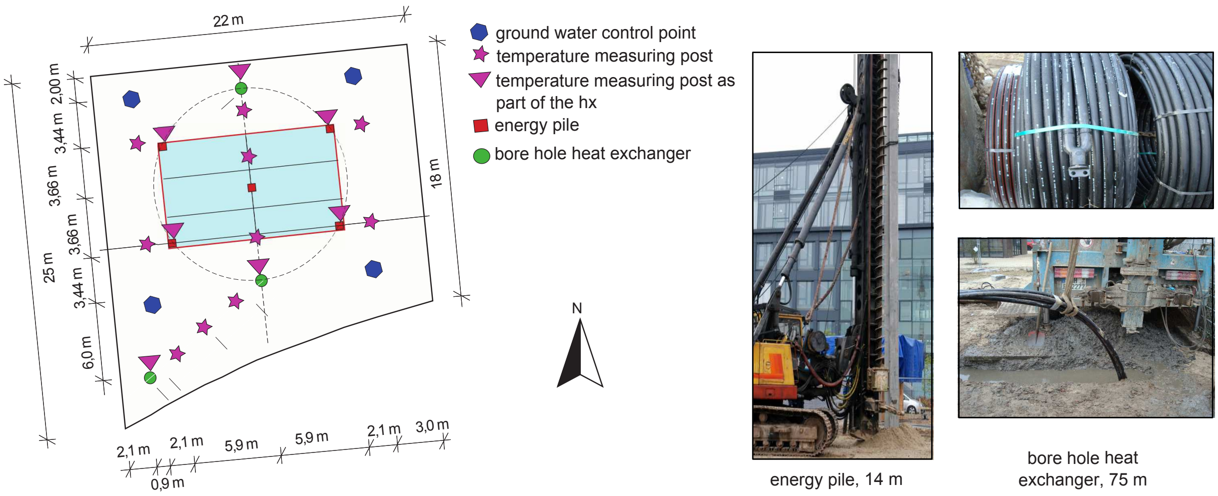

Figure 3: Location of the energy piles, the bore holes and the measurement devices for the pilot installation.

2. PILOT INSTALLATION

The pilot installation bases on the thermodynamic principles of the hybrid system introduced in (Wilson Casas 2005). The pilot plant integrates a desiccant assisted air conditioning system in a complete system based on renewable heat sinks and heat sources.

2.1 Thermodynamic basics of the hybrid system

The advantage of the hybrid system lies in the separation of cooling and dehumidification. This can be realized by the use of a desiccant wheel. The wheel consists of a honey combed structure coated with desiccant materials, such as lithium chloride. For the regeneration of the desiccant wheel a regeneration air heater (RAH) is needed.
The desiccant wheel as part of the air conditioning process is illustrated in **Figure 4a**. In **Figure 4b** the thermodynamic process of a conventional and hybrid process is illustrated in the psychometric chart.
In the conventional process the dehumidification is realized by cooling below the dew point which demands heat sinks of a low temperature level e.g. 10°C (50°F). This can rarely be provided by renewable heat sinks e.g. geothermal energy. In a hybrid system outdoor air (ODA) is dried in the desiccant wheel (1-2) and precooled by passing the rotating heat exchanger (2-3). The pre-dried air (3) is supplemental cooled in a water/air heat exchanger (3-4) to achieve supply air conditions (4). For the regeneration of the desiccant wheel the room air is pre-heated in the rotating heat exchanger (5-6) and supplemental heated in the regeneration air heater (6-7) to the regeneration air temperature. The temperature level of the regeneration air depends on the selected desiccant. The desiccant of the pilot installation is lithium chloride which needs a temperature of 40 °C to 70 °C (104°F to 158°F) for regeneration. The warm air (7) regenerates the desiccant wheel (7-8) before leaving the process (8). The separation of cooling and dehumidification brings several advantages. On the one hand, heat sinks on a temperature level above the dew point can be used e.g. shallow geothermal energy and on the other hand, the energy demand for cooling is reduced (see **Figure 4b**).

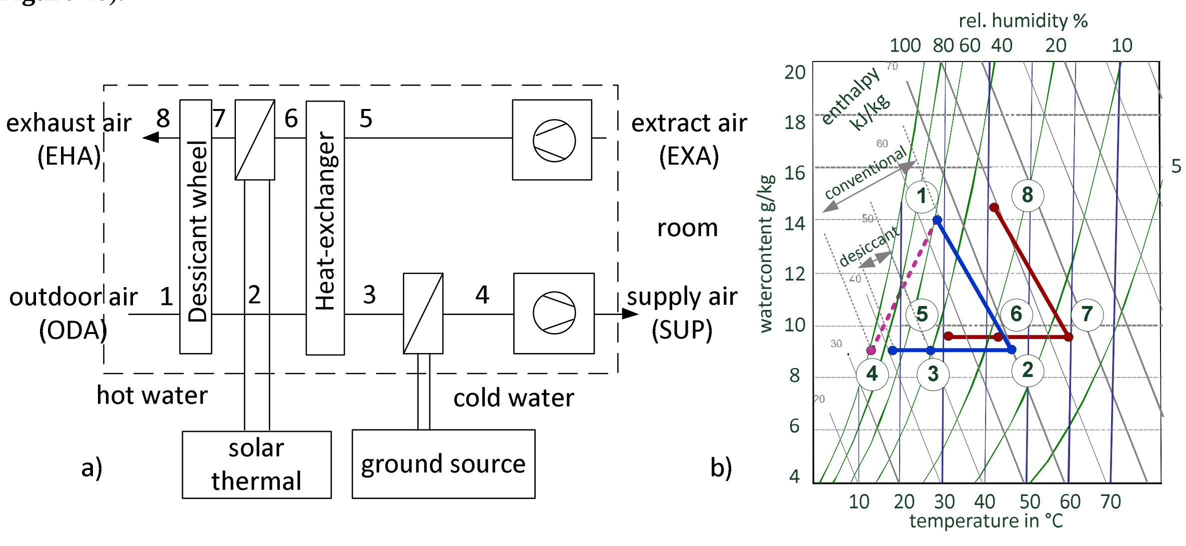

Figure 4: Process scheme of the hybrid system with psychometric chart.

2.2 Pilot installation of the hybrid air conditioning system

The principles of the installed air conditioning system are shown in **Figure 5**. Additional to the common hybrid system known from Parmar & D.A.Hindoliya (2011) this system includes a bypass to reduce the auxiliary power.

The bypass is installed below the supply air channel and above the extract air channel and allows bypassing the desiccant wheel, the rotating heat exchanger with the cooling/heating unit and the total system.
The advantages of the separation for dehumidification and cooling are significant but not always necessary. The outdoor conditions as well as the sensible and latent loads decide if the use of the desiccant wheel is necessary or not. For specific outdoor conditions the fresh outdoor air can be used without condition. Therefore it is important to save the pressure losses over the components by bypassing. Especially the desiccant wheel with the honey combed structure has relative high pressure losses which have to be counted for the supply and the extract air stream. The use of the bypass for saving additional pressure losses results in a demand oriented hybrid system.

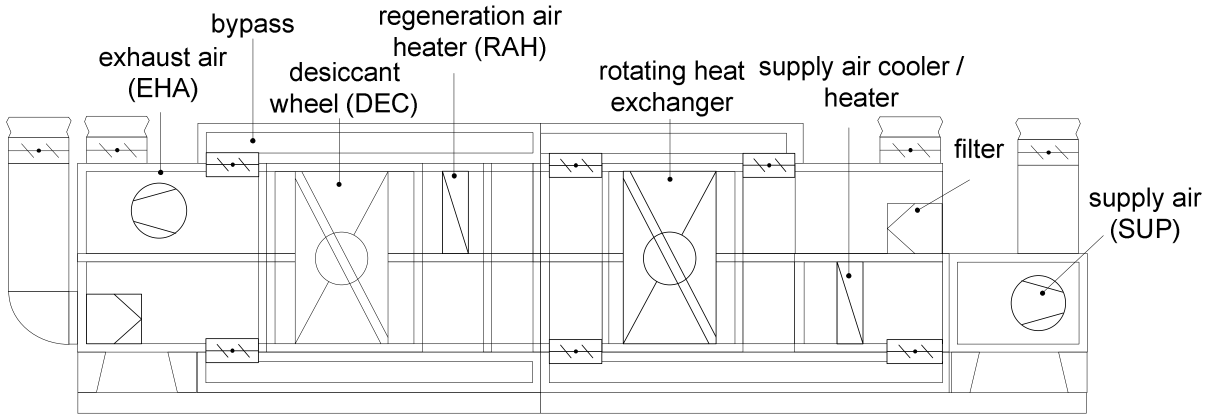

Figure 5: Scheme of the desiccant assisted air conditioning system as part of the pilot plant installation.

The air conditioning system is connected to the cold and warm water circuit shown in **Figure 6**. The warm side includes the solar thermal system, the stratified heat storage, the district heating network as well as a connection to the condenser side of the heat pump. The regeneration air heater, the supply air heater and the floor heating system are supplied by the warm side.
The solar thermal system includes 20 m² flat panels oriented to the south (see **Figure 2**). The stratified heat storage has a volume of 1000 liter and an extra heat exchanger for the connection to the solar system. The district heating network belongs to the local network company which has a mix of several heat sources e.g. gas, biomass and combined heat and power. The primary energy factor for the local heating network is 0.568. The supply air heater and the regeneration air heater seen in Figure 5 are a part of the air conditioning system.
The cold water circuit is connected to five energy piles and two bore hole heat exchangers, to a phase change slurries storage (PCSs) and to the evaporator side of the heat pump. For cooling purposes, the condenser side of the heat pump is connected to an extra bore hole heat exchanger to reduce the condensing temperature. The heat pump can be used as cooling or heating device. The cold side is connected to the radiant beams, the floor cooling system and the air cooler. The air cooler or the floor cooling system can be swapped by a 3-way-valve from cooling to heating.
The energy piles have a length of 14 m with a surface area of 0.1225 m² and due to scientific purposes different arrangements of the pipes (Ma and Grabe 2010). The three bore hole heat exchanger have a length of 75 m each. Two of the bore hole heat exchanger can be integrated in the cooling circuit, the third can be used as additional heat sink for the chiller.

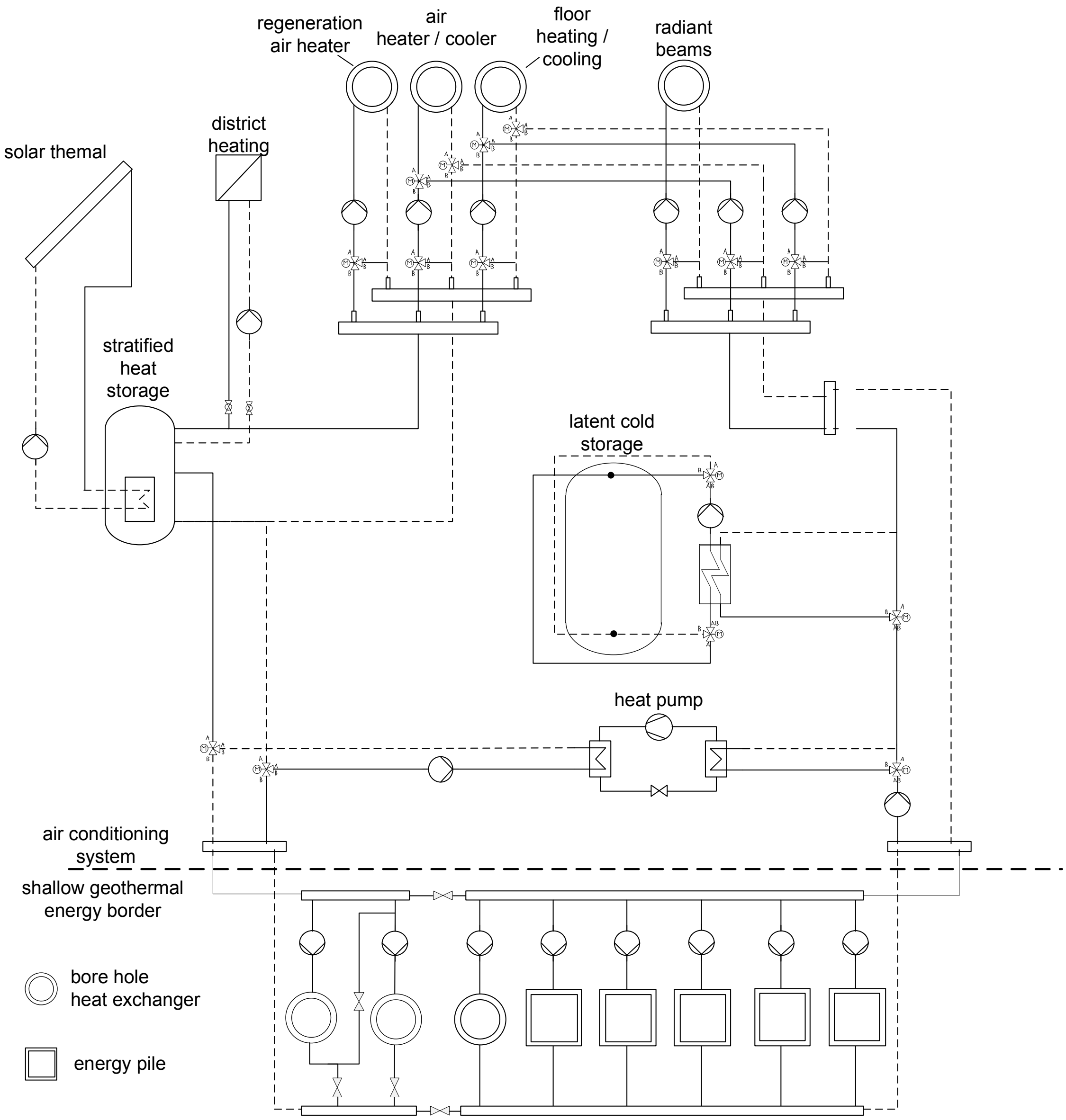

Figure 6: Scheme of the cold and warm water circuit of the pilot installation.

3. MODELING OF THE AIR CONDITIONG SYSTEM

On the one hand, the pilot installation allows an experimental investigation of several ways for an ecological and environmental friendly air conditioning system. On the other hand, the local climate conditions as well as the fixed components limit the experimental investigations. System models, calibrated with experimental data, can help to overcome these problems because it allows the analysis of non-existing configurations or plant extensions. Several tools for different approaches are used for system modeling. For example, the system models of the building and part of the solar thermal system have been realized by a system model based on EnergyPlus® V. 7.4. The system model of the HVAC-system including the desiccant wheel is an extension of existing components and libraries in Dymola Modelica.

3.1 Building

The system model of the building is designed in Google SketchUp® and implemented in EnergyPlus®. The experimental data are used for the validation of the models. **Figure 7** shows the model of the office building with the validation of the system model by using the calculation rules of VDI 2078 for the cooling load. The advantage of using EnergyPlus® for the building model is on the one hand the simple implementation of the geometrical building structure and on the other hand the possible coupling to other system models by using tools e.g. **B**uilding **C**ontrol **V**irtual **T**est **B**ed 1.0 (BCVTB). The validation shows a different in the time behavior which can be explained by the different capacity of the extra light reference building of the VDI 2078 and the building model.

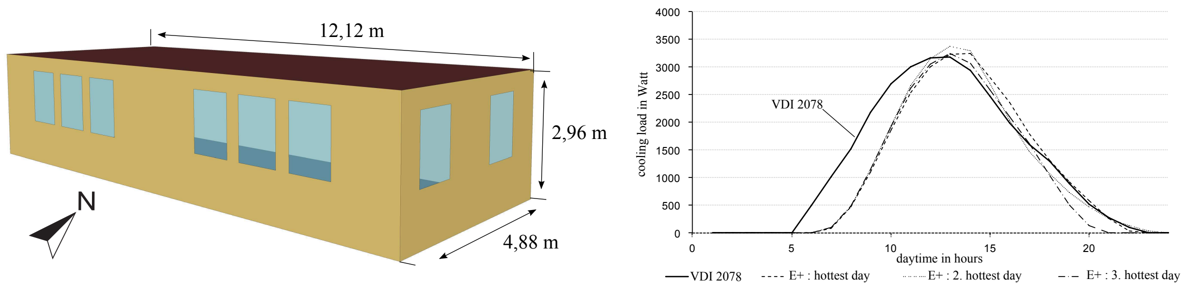

Figure 7: Geometric model structure of the building model based on Google SketchUp® and EnergyPlus® .

Table 1 shows the configuration data for the building envelope. The wall panels base on a sandwich structure with a metal plate wall on the surroundings and 100 mm insulation for the filling. The floor and the roof have an additional particle board which is situated under the floor cooling / heating and the floor pavement.

Table 1: Configuration data for the building envelope of the building model.

	thickness in m	heat conduction in W/mK	density kg/m³	heat capacity In J/(kg K)
metal plate wall	0,0005	45,28	7824	500
insulation	0,1	0,03	43	1210
particle board wall/roof	0,008	0,16	800	1090
particle board floor	0,022	0,16	800	1090

3.2 Heating, Ventilation and Air Conditioning

The HVAC-library is based on the modeling language Modelica and part of the project. The modeling language Modelica is a freely available, object-oriented language for the modeling of large, complex and heterogeneous physical systems. Within this work the commercial Modelica simulation environment Dymola, abbreviation of **Dy**namic **Mo**deling **La**boratory is used. In addition to the environment, a graphical editor for model editing and browsing is included.

The physical modeling of the HVAC components allows the detailed implementation of specific problems and therefore supplies system models free of any border (Joos, Schmitz, and Casas 2008; Wilson Casas, Prölß, and Schmitz 2005; G. Schmitz and Casas 2002). For example, the model of the desiccant wheel as part of the HVAC-library can be used for an optimization of the wheel parameter or system control as well as for realizing table-based numerical approximation. These numerical approximations are not dynamic but less complex and easy to implement in other systems e.g. online control of the desiccant wheel.

4. RESULTS

By using renewable heat sources and heat sinks it is possible to run an ecological and environmental friendly air conditioning system. Anyway, it is important to consider that this kind of system still needs electric energy due to the auxiliary power. Compared to a conventional air conditioning process even more auxiliary power is needed through running the desiccant wheel and the geothermal pumps. The influence of the auxiliary energy on the total energy demand can be seen in **Figure 8**. In **Figure 8** the primary energy consumption of the desiccant assisted air conditioning process to a conventional process is compared. Due to the use of renewable heat sources and heat sinks it is possible to significantly decrease the primary energy consumption. Anyway, the energy consumption of the electric pumps or the ventilation system increases. This increase results from the electric energy for the additional geothermal pumps and for the additional pressure losses due to the desiccant wheel. Please note, that the data were collected by focusing on a time period with dehumidification and cooling demand.

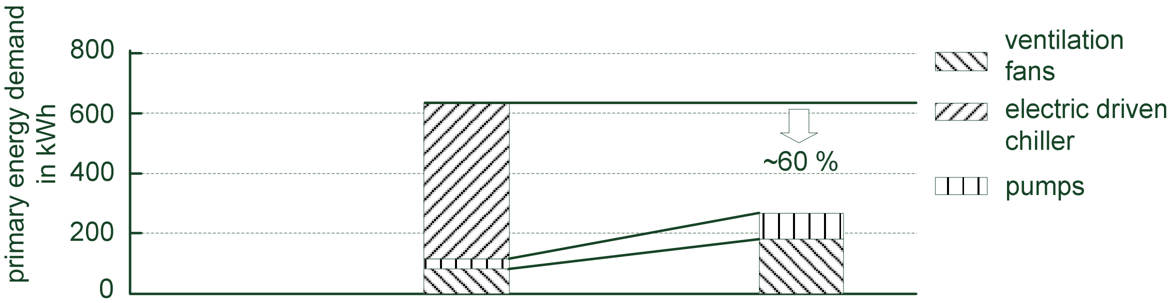

Figure 8: Primary energy demand for the conventional reference process compared to the hybrid process for the summer period 2010 for selected conditions (Wrobel and Schmitz 2010).

The efficiency of the shallow geothermal energy as heat sink can be described similar to a conventional system by the coefficient of performance (COP).

Table 2: Results of the geothermal performance for the summer period of the years 2009 and 2010 (EP: energy pile, BHE: bore hole heat exchanger)

summer period 2009 and 2010 geothermal heat exchanger	EP1	EP2	EP3	EP4	EP5	BHE1	BHE2
operating hour [h]	380,8	414,9	419,2	390,3	333,0	523,3	429,1
heat [kWh]	161,3	189,4	197,6	170,8	147,3	887,9	590,6
pump energy [kWh]	14,0	30,6	25,0	13,1	10,8	39,0	33,4
specific energy [W/m]	32,2	34,7	36,5	33,2	33,8	22,7	18,4
COP [-]	11,4	6,1	8,0	12,9	13,6	22,7	17,6

The time of specific outdoor conditions as well as the internal sensible and latent load plays a crucial role in the evaluation of the process.

Figure 9 shows the time period of specific conditions within the year 2011 for the whole day and the office hours from 7 am to 9 pm. The BP stays for operating point of demand oriented air conditioning system. The operating points can be summarized as follows:

- BP0: The outdoor air conditions are equal to room conditions equivalent to the comfort standards.
- BP1: The water content of the outdoor air is above 9.5 g/kg and the temperature is below 20°C.
- BP2: The water content of the outdoor air is above 9.5 g/kg and the temperature is above 20°C.
- BP3: The water content of the air lies within a comfortable range (6 g/kg-9.5 g/kg) and is below 20°C.
- BP4: The water content of the air lies within a comfortable range (6 g/kg-9.5 g/kg) and is above 24°C.
- BP5: The water content is below 6 g/kg.

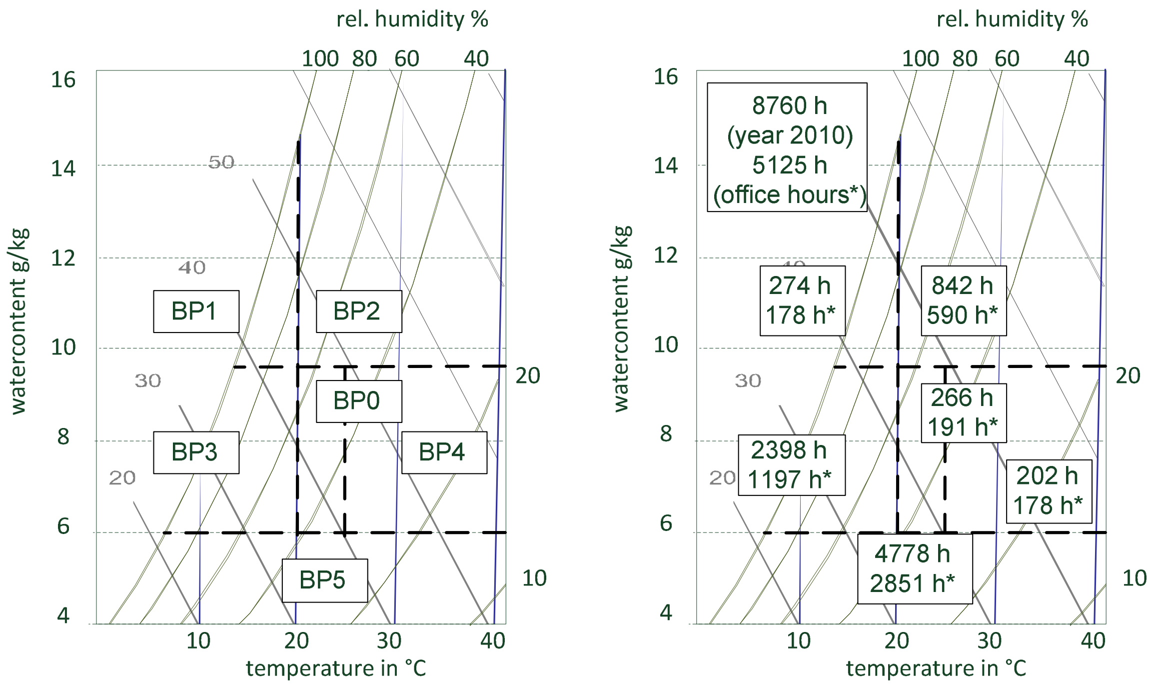

Figure 9: Psychometric chart with operating points and hours of the outdoor conditions for the year 2011 (BP: operation point, german: Betriebspunkt).

6. CONCLUSIONS

The experimental and simulation results of the pilot installation of the hybrid air conditioning system based on renewable heat sources and heat sinks can be summarized as follows:

- An ecological and environmental friendly air conditioning system is possible and can save up to 60 % primary energy.
- The pressure losses have a significant influence on the total primary energy demand and cannot be neglected.
- Bypassing components for a demand oriented air conditioning system has a higher control demand but is more energy efficient.
- The use of a desiccant wheel enables the usage of shallow geothermal energy as heat sink and solar thermal energy as heat source.
- The separation of dehumidification and cooling and ventilation and cooling has a high potential in energy savings for air conditioning process.
- The uncertainties of the measurement devices e.g. humidity probes, have to be considered especially for the model validation. First investigations showed that the water content has a significant influence on the system control and therefore on the overall efficiency.

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